MERCURY POLLUTION

Buyat & Totok Bay
North Sulawesi
Indonesia

FINAL REPORT

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For:
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Indonesia

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Mission Report — Investigation Into Suspected Mercury Contamination in People Living Near Buyat Bay, Manado, North Sulawasi, Indonesia

National Institute for Minamata Disease

(This Mission Report was prepared in collaboration with the following Study Group)

Study Group for WHO Indonesia-Project Proposal (2004)

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8th September 2004

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1. Background

This is the report of a collaborative mission carried out by NIMD (National Institute for Minamata Disease) in response to the request of WHO, Indonesia. The main purpose of this study was to carry out an environmental health assessment of the villagers living near by Buyat Bay, Manado, North Sulawasi, Indonesia.

A submarine system of submarine tailing disposal of mining operations to the Buyat Bay was begun by a gold mining company, P.T. Newmont Minahasa Raya. It was reported that 2000 tons per day of tailings were deposited the Buyat Bay (Laust; 2004). Some of the villagers are suffering from cause-unknown diseases such as migraine-like headaches, skin disease and sizeable tumors appearing on various body parts.

The evaluation of the potential hazards of mercury exposure to inhabitants was performed by analyzing both total and methylmercury concentrations in the hair of Buyat Bay. As a control group, a near village Totok Bay neighboring Buyat Bay was selected for the purpose of population comparison. Totok Bay is separated from Buyat Bay by a long peninsula as shown in Figure 1, and the villagers do not exhibit the symptoms seen in the Buyat Bay villagers.

The mercury pollution in Buyat Bay villages/areas might be the results of operations by a big gold mining company and some artisanal gold mining around the river entering Buyat Bay. Totok Bay villagers might also be contaminated by artisanal gold mining around the river which enters Totok Bay. The main difference is the tailings being deposited into Buyat Bay by a big gold mining company.

It is generally recognized that the best indications of human exposure to methylmercury are the mercury concentrations in hair and red blood cells. In this mission, hair samples were collected to ascertain the methylmercury and other heavy metal exposure levels of the people. Limited environmental samples (fish, soil, and water) were also collected to estimate how the people might be exposed to methylmercury and other heavy metals. All the samples were analyzed at the NIMD to determine the mercury and other heavy metal concentrations. In addition, cyanide analysis of water samples were performed by Metocean Environment, Inc. and pathological analysis of tumors in fish samples was performed by Yukifumi Nawa, MD, PhD, Vice-President (Research and Planning) of University of Miyazaki. This report summarizes the results of the findings.

2. Mission Objectives

The objectives of the mission are as follows:

1. Assess MeHg exposure levels in villagers living near Buyat Bay.

2. Assess MeHg levels in fish caught in Buyat Bay.

3. Assess exposure levels of people to other heavy metals (As, Mn, Cd, Se etc.).

4. Assess contamination levels of the environment (soil and sea water) to mercury, cyanide and heavy metals.

5. Assess the tumors in fish caught in Buyat Bay.

6. Inter-laboratory comparison of Hg measurement quality. Exploration of possible future cooperation with public health authorities in Jakarta and Manado, Indonesia.

3. Survey

3-1. Samples for study

From 8-11 August 2004 a field visit and fact finding mission was conducted to obtain more information on suspected methylmercury pollution due to gold mining in Buyat Bay, Manado, North Sulawasi .

The members of the mission were:

Mineshi Sakamoto, Ph.D. (Dept. of Epidemiology, Section Chief, National Institute for Minamata Disease, Japan)
Ir. Jan A. Speets (Advisor Environmental Health, WHO Indonesia)
Suprianto Margono, Ph.D. (Directorate of Water and Sanitation, Ministry of Health, Indonesia)

H. Wan Alkadri, M.D. (Director Environmental Health, Ministry of Health, Republic of Indonesia) joined the team in Manado on 10th August 2004. The team was accompanied by local health authorities who provided excellent assistance.

The team was also accompanied by three police agents was able to work without any disturbance, and to concentrate on the tasks of conducting interviews with Buyat Bay

villagers and taking samples for later analysis in Japan. The evaluation of the potential hazards of mercury exposure to inhabitants and environment was performed by analyzing hair and environmental samples from Buyat Bay Village. As control, samples were collected from Totok Bay Village for the purpose of pollution comparisons. Totok Bay is separated from the Buyat Bay by a long peninsula as shown in Figure 1, and the villagers do not exhibit the symptoms seen in Buyat Bay villagers. Samples were collected mainly on 9 August, 2004.

Hair

Thirty-five hair samples were collected from Buyat Bay villagers to assess methylmercury and other heavy metals exposure. Another 16 hair samples were collected from Totok Bay Village as a control. About 60 of hair samples were cut with scissors from the root and placed into small bags which were than sealed.

Health questionnaires

All persons who gave hair samples were interviewed by questionnaire regarding health complaints such as sensory disorder, ataxia, hearing impairment, speaking impairment, headache, and stomachache.

Fish

Fifteen fish samples from Buyat Bay and 9 samples from Totok Bay were collected to assess methylmercury levels, respectively. Fish meat was cut from the back side. Samples were stored with ice during the sample collection and stored in a freezer thereafter.

Water

Four samples were collected by submerging half-liter pre-cleaned a plastic bottle about 10 cm below the surface of mouths of the rivers and seashores in Buyat and Totok Bays. One tap water sample from Buyat Bay Village which had been in use for about 3 months was also collected. The samples were stored in a refrigerator, avoiding sunlight exposure until analysis.

Sediment

Four surface sediment samples were collected from the mouth of the river and seashore near the river in Buyat Bay and from the mouth of the river and seashore near the river in Totok Bay.

Fish with tumor

Two fish with tumors on their bodies, 2 fish without tumors and 6 tumors alone were collected in Buyat Bay Village. The samples were put into 5% formaldehyde and stored

in a refrigerator until analysis.

3-2 Determination of total and methyl mercury in samples

Hair and urine

Hair samples were washed with neutral cleanser and acetone, dried at room temperature, then cut with scissors. Approximately 10 mg of the cut hair sample was used for total mercury analysis and methylmercury analysis, respectively. Total mercury was determined by cold vapor atomic absorption spectrophotometry (CVAAS) according to the method of Akagi and Nishimura (25). The method involves sample digestion with HNO_3 $HClO_4$ and H_2SO_4 followed by reduction to Hg^0 by $SnCl_2$. The detection limit was 0.1 ng/g. Accuracy was ensured by using certified reference material (DORM-2; dogfish muscle prepared by the National Research Council, Canada) as the quality control material; the Hg concentration found averaged 4.53 μg/g, as compared to the assigned value of 4.64 $\pm$ 0.26 μg/g. The total analytical precision of this analysis was estimated to be 3.9%.

Methylmercury contents in hair and fish were analyzed by the method as described by Akagi and Nishimura (Advance in Mercury Toxicology, 1991). Ten mg of fine-cut hair samples were weighed and placed in a Pyrex test tube with cap, to which two drops of ethanol, 5 ml of 2 N and a small amount of de-fatted cotton were added to prevent the of hair sample from floating. The tube was capped tightly and then heated at 100 °C for 5 min. After being mixed and cooled to room temperature, 1 ml of hydrochloric acid extract was transferred to another 10 ml test tube with cap and extracted with toluene. Methylmercury in the toluene extract was subsequently measured by ECD-gas chromatography (ECD-GLC, Yanaco G-6800). The detection limit was 1 ng/mg for 100 g of the sample.

Standard human hair samples obtained from NIES (National Institute for Environmental Sciences) were measured for certification.

Water

Sample water was filtered through filter paper. Total mercury contents in water samples was analyzed by the method described by Akagi and Nishimura (Advances in Mercury Toxicology; 1991), with minor modifications. Two hundred ml of a water sample in a separatory funnel was mixed with 2 ml of 20 N sulfuric acid and 1 ml of 10 % hydroxylamine hydrochloride and allowed to stand for 20 min. After the addition of 1 ml of 10% ethylenediaminetetra acetic acid tetrasodium salt, the sample was extracted with 5 ml of purified 0.01% dithizone in toluene. The sample was left until it separated and the water layer was discarded. Four ml of the toluene layer was then transferred into a 50 ml volumetric flask and evaporated to until dry using a rotary evaporator. To the residue 1 ml of water, 2 ml of nitric aid and perchloric acid (1:1) and 10 ml of sulfuric acid were added and heated on a hotplate at 250℃ for 30 min. After cooling, the digested sample was added to water to equal 50 ml and analyzed by cold vapor atomic

absorption spectrometry. The detection limit was 0.01 ng/l for 1 L of sample.

Sediment

Soils and sediment samples were sieved through a 340 μm mesh sieve, and part of the sample was used for determining the water content. The mercury contents were expressed on the basis of dry weight. Food samples were cut into pieces and the mercury contents were expressed on the basis of wet weight. Total mercury contents in food and soil/sediments were analyzed by the method descried by Akagi and Nishimura (Advances in Mercury Toxicology; 1991), with minor modifications. A known amount of sample was placed in a 50 ml volumetric flask, to which 1 ml of water, 2 ml of nitric aid and perchloric acid (1:1) and 10 ml of sulfuric acid were added and heated on a hotplate at 250℃ for 30 min. After cooling, the digested sample was made up to 50 ml with water and analyzed by cold vapor atomic absorption spectrometry. The direction limit was 0.1 ng/g for 1 g of the sample.

3-3 Determination of total cyanide in water samples

Total cyanide compound (cyanide ion, cyanogens chloride, and thiocyanic acid ion) were analyzed by auto analyzer in METOCEAN Corporation using 4-pyridinecarboxylic acid-pyrazolone absorption method.

3-4 Determination of other metals in hair samples

All of the metals were analyzed by ICP-MS (POEMS 3, Jarrell Ash Corporation). About 50 mg of hair samples were digested with 1 ml NHO_3 by microwave digestion system (MDS 200, CEM Corporation).The values of the human hair certified reference material (NEES No. 13) prepared by National Institute for Environmental Studies were referenced in the end of Table 7 (Yoshinaga J. et al. 1997)

4. Results and Discussion

4-1 Total and methylmercury in hair

In this mission, total and methylmercury concentrations in hair were analyzed for methylmercury exposure level from the environment.

The mercury concentrations in hair show lognormal distribution in the ordinal populations. Therefore, the mercury concentration was expressed by the geometric mean.

As shown in Table 1, the geometric mean of the mercury concentrations in hair was 2.65 μg/g for the Buyat Bay villagers and 3.72 μg /g for the Totok Bay villagers. Geometric mean of the methylmercury concentrations in hair was 2.42 μg/g for the Buyat Bay

villagers and 3.2 μg/g for the Totok Bay villagers. About 90% of total mercury was the methyl form suggesting that there is no external exposure of mercury vapor or inorganic mercury. The mean mercury concentration in the hair of the Totok Bay villagers was about 1.5 times higher than that of the Buyat Bay villagers.

Mercury concentration in hair is one of the best indicators of methylmercury pollution. The mean hair mercury concentrations of the Buyat Bay and Totok Bay villagers were more than 20 times lower than the threshold levels of 50-125 μg/g (WHO, IPCS, Environmental Criteria 101: Methylmercury, 1990). The hair mercury levels are similar to those in the Japanese population (Yasutake et al. 2004). Fish consumption is the main source of mercury accumulation in humans. Since the people of this area consume much fish, methylmercury accumulation of these populations is comparatively as high as the Japanese. However, the mercury levels in Buyat Bay villagers were not high enough to cause methylmercury poisoning.

4-2 Total and methylmercury in fish

Most human exposure to methylmercury is through fish and shellfish. Generally, the larger fish higher up the food chain contain higher of levels methylmercury than smaller fish. Mercury concentration in fish is one of the best indicators of the aquatic environmental mercury pollution. Most of mercury in fish is methylmercury.

As shown in Table 2, most of the mercury in fish was methylmercury. The mean mercury level in the fish was 0.24 μg/g in Buyat Bay and 0.15 μg/g in Totok Bay. The fish mercury level in Buyat Bay was about 1.5 times higher than that in Totok Bay. However, the mercury levels in fish were within the normal range (Mahaffy, 2004). At the time of the outbreak of Minamata disease, average mercury concentration in fish was higher than 10 μg/g.

The size and species of fish caught in the bays were completely different. Therefore, the difference in the mercury level will not indicate the difference in methylmercury contamination levels between the bays. The mercury levels in fish do not indicate any hazardous methylmercury pollution in the environments.

4-3 Fish consumption and frequency of complaints

Most of the people living in Buyat and Totok Bay villages ate fish 3 times per a day indicating that both of the villagers depended on fish as their protein source (Table 3).

About 70% (25/35) villagers complained of headache symptoms in Buyat Bay Village and about 20% (3/16) complained of the symptom in Totok Bay Village. About 30% (12/35) villagers complained of the appearance of tumors in Buyat Bay village and about 10% (2/16) complained of the symptom in Totok Bay Village. Headache and tumor were the most common symptoms of Buyat Bay Villagers. Only 2 villagers in Buyat Bay reported symptoms of sensory disorder and 1 reported ataxia which are typical symptoms of methylmercury intoxication.

4-4 Total mercury concentrations in sediment

As shown in Table 4, sediment mercury concentrations in dry weight were 0.10 μg/g in the river, 0.06 μg/g in the mouth of the river and 0.04 μg/g in the seashore of Buyat Bay. On the other hand, they were 7.41 μg/g at the mouth of the river and 4.06 μg/g along the seashore of Totok Bay.

These results suggest that mercury is entering to the sea through the rivers in both bays. However, the mercury level was much higher in Totok than in Buyat Bay indicating that a large gold mining company is not contributing greatly to mercury contamination in Buyat Bay. Mercury release from artisanal gold mining is deemed to be greater in the river emptying into Totok Bay.

4-5 Total mercury concentrations in water

As shown in Table 5, water mercury concentrations were 1.4 ng/L in the river, 1.7 ng/L in tap water and 0.2 ng/L in the seashore of Buyat Bay. On the other hand, they were 7.7 ng/L at the mouth of the river and 2.8 ng/L along the seashore of Totok Bay.

The results were similar to the results of sediment mercury concentrations. These results also suggest that the mercury level was much higher in Totok than in Buyat Bay indicating that a large gold mining company is not contributing greatly to mercury contamination in Buyat Bay. Mercury release from artisanal gold mining is seemed to be greater in the river emptying into Totok Bay.

4-6 Total cyanide concentrations in river and seashore water of Buyat and Totok Bays.

As shown in Table 6, water cyanide concentrations were less than 0.01 mg/L in the river, tap water and in the seashore of Buyat Bay. Also, they were less than 0.01 mg/L at the mouth of the river and in the seashore of Totok Bay. These results suggest that both of the areas are not polluted by cyanide.

4-7 Other metals concentrations in hair of villagers living near Buyat and Totok Bays.

As shown in Table 7, all of the metal concentrations in hair of villagers living near Buyat and Totok Bays showed within normal levels. These results suggest that both of the people living in these areas are not polluted to the toxic levels by the metals.

5. Conclusion

1 The total and methylmercury concentrations in hair of Buyat Bay villagers and Totok Bay villagers were not high enough to cause methylmercury intoxication. Health effects due to methylmercury exposure were not observed among the Buyat Bay villagers. Further, the villagers' methylmercury exposure level seemed to be higher in Totok Bay than in Buyat Bay.

2 The total mercury in soil and water samples suggested that the environment in Totok Bay was more contaminated with mercury than in Buyat Bay. However, the environment has not become highly contaminated with methylmercury at present as indicated by the low mercury levels in fish.

3 The total and cyanide concentrations suggested that the environment in Buyat and Totok Bays are not contaminated with cyanide.

4 The total and metals concentrations in hair of Buyat Bay villagers and Totok Bay villagers were not high enough to cause intoxication.

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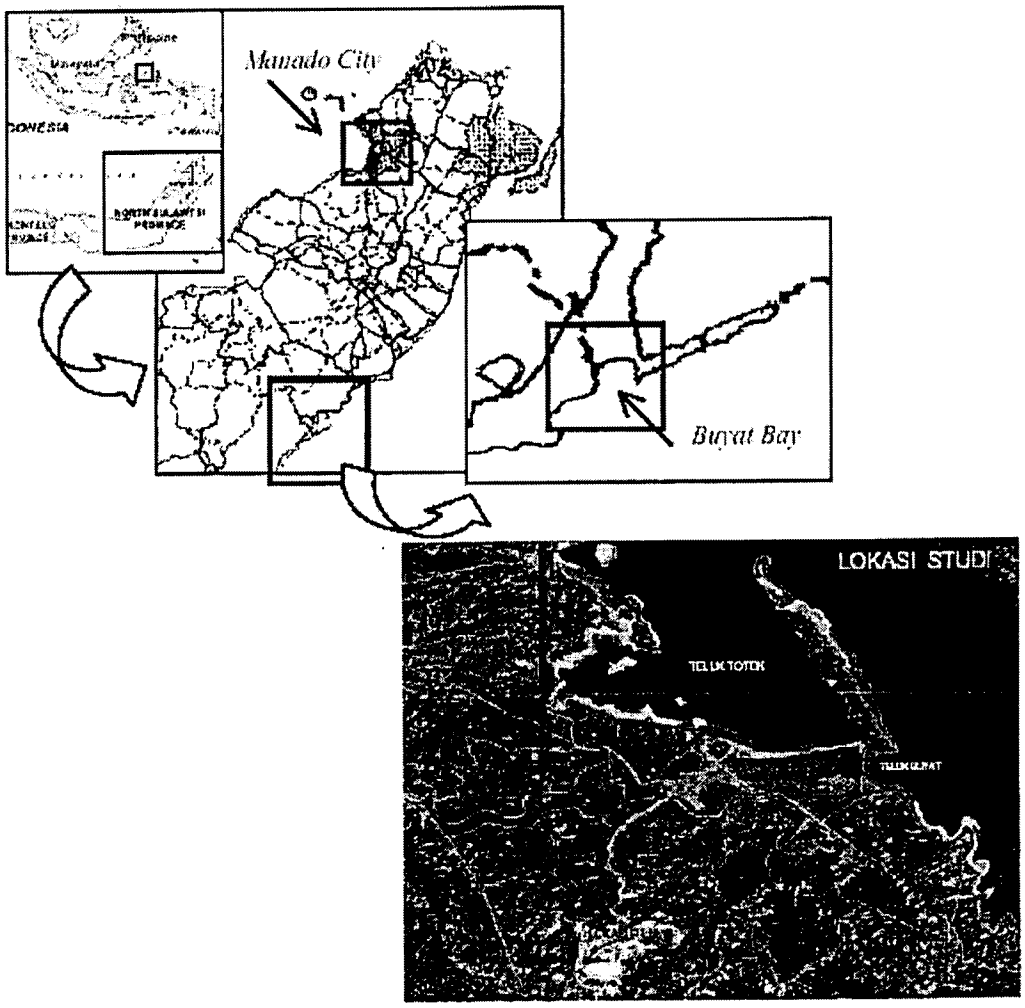

Figure 1 Location of study areas in Buyat Bay and Totok Bay, North Sulawasi, Indonesia

Table 1. Total and methylmercury concentrations in villagers living near Buyat and Totok Bays.

		N	Geomean (μg/g)	(min - max)	Age±SD
Buyat	T-Hg	35	2.65	(0.77 - 7.64)	30.3±15.1
	Me-Hg	35	2.42	(0.53 - 7.73)	30.3±15.1
Totok	T-Hg	16	3.72	(1.54 - 9.65)	34.8±16.9
	Me-Hg	16	3.22	(0.61 - 9.60)	34.8±16.9
Total	T-Hg	51	2.94	(0.77 - 9.65)	31.7±15.7
	Me-Hg	51	2.60	(0.53 - 9.60)	31.7±15.7

					Hair (Total Hg)	Hair (Methyl Hg)
	No.	name	sex	age	μg/g	μg/g
Buyat	1	NT	♀	50	3.10	2.69
	2	YM	♀	28	1.40	1.39
	3	SM	♀	52	3.60	3.48
	4	NC	♀	21	5.56	4.71
	5	SM	♂	50	3.73	3.50
	6	SP	♀	25	0.91	0.69
	7	MR	♀	44	2.56	2.00
	8	SL	♀	6	2.59	2.44
	9	ED	♀	34	1.26	0.81
	10	AL	♀	46	2.18	1.83
	11	SP	♀	52	1.63	1.61
	12	SM	♀	21	2.67	2.49
	13	RB	♂	28	4.98	4.41
	14	SM	♂	35	4.62	4.51
	15	BM	♂	32	2.27	1.89
	16	FP	♀	13	1.06	1.03
	17	NB	♀	11	2.17	1.85
	18	LS	♀	32	1.33	1.10
	19	HM	♀	39	2.74	2.42
	20	PP	♂	3	1.80	1.57

	21	JP	♀	32	2.07	1.83
	22	RC	♂	15	2.66	1.68
	23	IC	♂	43	4.68	4.05
	24	SM	♂	40	3.01	3.14
	25	SM	♂	38	4.83	4.30
	26	AM	♀	3	2.38	1.88
	27	KN	♂	59	5.59	5.44
	28	MB	♀	23	2.24	2.00
	29	HC	♀	25	3.15	3.05
					Hair (Total Hg)	Hair (Methyl Hg)
	No.	name	sex	age	μg/g	μg/g
Buyat	30	AL	♀	21	2.15	2.00
	31	FB	♂	0.8	0.77	0.53
	32	SM	♀	31	2.22	2.16
	33	JB	♂	34	7.12	7.06
	34	SD	♂	33	4.83	4.67
	35	SE	♂	39	7.64	7.73
Totok	36	HM	♂	52	2.94	2.88
	37	AH	♂	40	4.21	3.93
	38	MM	♂	24	5.07	5.00
	39	SR	♂	44	1.54	1.12
	40	HM	♂	52	4.64	4.44
	41	AH	♂	47	3.12	2.96
	42	BG	♂	35	6.69	6.08
	43	AS	♂	41	9.65	9.60
	44	KS	♂	18	2.42	2.35
	45	SS	♀	48	4.09	3.96
	46	SI	♀	27	4.76	4.58
	47	AS	♀	6	1.67	1.38
	48	SS	♀	14	5.32	5.33
	49	AD	♀	14	1.72	0.61
	50	AG	♂	67	6.70	5.76
	51	PG	♂	28	3.04	2.30

Table 2. Total and methylmercury concentrations in fish caught in Buyat and Totok Bays.

		N	AV (μg/g)±SD	(min - max)
Buyat Bay	T-Hg	15	0.243±0.143	(0.054 - 0.603)
	Me-Hg	15	0.215±0.165	(0.051 - 0.603)
Totok Bay	T-Hg	9	0.147±0.148	(0.012 - 0.365)
	Me-Hg	9	0.134±0.137	(0.011 - 0.330)
Total	T-Hg	24	0.207±0.175	(0.012 - 0.627)
	Me-Hg	24	0.185±0.157	(0.011 - 0.603)

	No.	Genus	Length cm	T-Hg μg/g	Me-Hg μg/g
Buyat Bay	1	Cheilinus diagrammus	16.6	0.18	0.16
	2	Pseudocaranx dentax	15.2	0.06	0.06
	3	Parupeneus trifasciatus	14.1	0.28	0.24
	4	Lutjanus lineolatus	12.5	0.56	0.43
	5	Lutjanus lineolatus	12.1	0.15	0.13
	6	Synodus uariegatus	15.3	0.63	0.60
	7	Epinephelus summana	12.6	0.11	0.10

	8	Lutjanus caeruleovittatus	9.7	0.33	0.28
	9	Balistapus undulatus	11.5	0.16	0.13
	10	Cephalopholis pachycetron	14	0.18	0.16
	11	Epinephelus summana	18	0.31	0.31
	12	Epinephelus teuvina	16.8	0.12	0.09
	13	Lutjanus lineolatus	13.2	0.48	0.42
	14	Lutjanus lineolatus	8.9	0.05	0.05
	15	Pseudocaranx dentax	16.3	0.05	0.05
Totok Bay	16	Pterocaesio marri	14.8	0.01	0.01
	17	Pterocaesio marri	14.7	0.01	0.01
	18	Caranx ignobilis	10	0.13	0.12
	19	Pseudocaranx dentax	10.2	0.02	0.02
	20	Terapon theraps	13.6	0.36	0.33
	21	Lutjanus rivulatus	8.4	0.35	0.33
	22	Gerres oyeha	9.5	0.30	0.27
	23	Euthynnus affinis	23.4	0.06	0.05
	24	Auxis rochei	20.4	0.07	0.06

Table 3. Fish consumption and frequency of complaints in villagers living near Buyat and Totok Bays.

										Hair	
			(A) Fish intake	(B) Symptoms						T-Hg	Me-Hg
	No.	occupation	times/day	sensory disorder	ataxia	headache	stomachache	other	comment	μg/g	μg/g
Buyat	1	Housewife	3	-	-	o	o	Hearing problem		3.10	2.69
	2	Housewife	3	-	-	o	-	Oispnen		1.40	1.39
	3	Housewife	3	o	-	o	-	Cramp	(A): No fish for 3 months	3.60	3.48
	4	Housewife	3	-	-	o	-	Neck Tumor→ not clear		5.56	4.71
	5	Fisherman	3	-	-	o	-	Cramp		3.73	3.50
	6	Housewife	3	-	-	o	-	/Cramp		0.91	0.69
	7	Housewife	3	-	-	o	-	-	(A): No fish for 1 month	2.56	2.00
	8	-	3	-	o	-	-	Cramp		2.59	2.44
	9	Housewife	3	o	-	-	-	-	(A): No fish for 1 month	1.26	0.81
	10	Housewife	3	-	-	o	-	-	(A): No fish for 1 year	2.18	1.83
	11	Housewife	3	-	-	o	-	Tumor, Cramp		1.63	1.61
	12	Housewife	3	-	-	o	-	-	(A): No fish for 1 month (Pregnant 7 months) (B): headache→ since 17 years old	2.67	2.49
	13	Fisherman	3	-	-	-	-	Itching		4.98	4.41
	14	Fisherman	3	-	-	o	-	Cramp		4.62	4.51
	15	Fisherman	3	-	-	o	-	Myalgia		2.27	1.89
	16	Student	3	-	-	o	-	Arthralgia	(A): No fish for 1 year	1.06	1.03
	17	Student	3	-	-	o	-	-	(A): No fish for 1 month	2.17	1.85

	18	Housewife	3	-	-	o	-	-		1.33	1.10
	19	Housewife	3	-	-	o	-	Cramp, Myalgia		2.74	2.42
	20	-	3	-	-	o	-	Myalgia		1.80	1.57
	21	Housewife	3	-	-	o	-	Myalgia in hand		2.07	1.83
	22	Student	3	-	-	o	-	Cramp		2.66	1.68
	23	Fisherman	3	-	-	-	-	Cramps a leg		4.68	4.05
	24	Fisherman	3	-	-	o	-	-	(A): No fish for 5 months	3.01	3.14
	25	Fisherman	3	-	-	-	-	-	(A): w/sashimi	4.83	4.30
										Hair	
			(A) Fish intake	(B) Symptoms						T-Hg	Me-Hg
	No.	occupation	times/day	sensory disorder	ataxia	headache	stomachache	other	comment	μg/g	μg/g
Buyat	26	-	3	-	-	-	-	Cough		2.38	1.88
	27	Fisherman	3	-	-	-	-	Neck Tumor, Cramps, Myalgia, Chest Pain		5.59	5.44
	28	Housewife	3	-	-	o	-	Cramps		2.24	2.00
	29	Housewife	3	-	-	o	-	-		3.15	3.05
	30	Housewife	3	-	-	o	-	-	(A): No fish for 1 month	2.15	2.00
	31	-	3	-	-	-	-	Cough	(A): No fish for 2 months	0.77	0.53
	32	Housewife	3	-	-	o	-	-		2.22	2.16
	33	Fisherman	3	-	-	-	-	Itching		7.12	7.06
	34	Fisherman	3	-	-	o	-	-		4.83	4.67
	35	Fisherman	3	-	-	-	-	LBP		7.64	7.73
Totok	36	Fisherman	3	-	-	o	-	-		2.94	2.88

	37	Fisherman	3	-	-	-	-	Cough		4.21	3.93
	38	Fisherman	5	-	-	-	-	-	(A): sashimi	5.07	5.00
	39	Fisherman	3	-	-	-	-	Cramps, Visual disorder	(A): sashimi (sometimes)	1.54	1.12
	40	Fisherman	5	-	-	-	-	Chest pain	(A): sashimi	4.64	4.44
	41	Fisherman	3	-	-	-	-	Cramps, Visual disorder, Cough	(A): sashimi	3.12	2.96
	42	Fisherman	3	-	-	-	-	-		6.69	6.08
	43	Fisherman	3	-	-	-	-	-	(A): sashimi	9.65	9.60
	44	Fisherman	3	-	-	-	-	-	(A): sashimi	2.42	2.35
	45	Housewife	3	-	-	o	-	Itching	(A): sashimi	4.09	3.96
	46	Housewife	3	-	-	o	-	-		4.76	4.58
	47	Student	3	-	-	-	-	-		1.67	1.38
	48	Student	3	-	-	-	-	-		5.32	5.33
	49	Student	3	-	-	-	-	-		1.72	0.61
	50	Fisherman	3	-	-	-	-	-	(A): sashimi	6.70	5.76
	51	Fisherman	3	-	-	-	-	-		3.04	2.30

Table 4. Total mercury concentrations in river and seashore sediments of Buyat and Totok Bays.

	Station	T-Hg (dry wt.) μg/g
Buyat Bay	River	0.10
	Mouth of river	0.06
	Seashore	0.04
Totok	River	7.41
	Seashore	4.06

Table 5. Total mercury concentrations in river and seashore water of Buyat and Totok Bays.

	Station	T-Hg ng/L
Buyat Bay	River	1.4
	Tap water	1.7
	Seashore	0.2
Totok	River	7.7
	Seashore	2.8

Table 6. Total cyanide concentrations in river and seashore water of Buyat and Totok Bays.

	Station	T-Cn mg/L
Buyat Bay	River	<0.01
	Tap water	<0.01
	Seashore	<0.01
Totok	River	<0.01
	Seashore	<0.01

Table 7. Other metals concentrations hair in villagers living near Buyat and Totok Bays.

		n	Geomean (μg/g)	AV(μg/g) ± SD	(min - max)
Buyat	As	34	0.463	0.495±0.188	(0.235 - 1.017)
	Cd	34	0.052	0.069±0.068	(0.011 - 0.387)
	Cr	34	3.911	5.438±5.599	(1.398 - 26.14)
	Ga	34	0.119	0.136±0.067	(0.028 - 0.280)
	Mo	34	0.053	0.056±0.018	(0.022 - 0.098)
	Sb	34	0.037	0.046±0.035	(0.013 - 0.149)
	Se	34	1.195	1.229±0.299	(0.735 - 1.977)
	Tl	34	0.003	0.004±0.002	(0.001 - 0.012)
	V	34	0.349	0.388±0.184	(0.095 - 0.952)
	Al	30	20.87	29.84±19.70	(0.064 - 96.22)
	Cu	34	8.873	9.648±3.455	(1.721 - 19.43)
	Mn	34	7.337	9.958±6.732	(0.505 - 24.5)
	Ni	34	1.166	1.580±1.483	(0.215 - 8.255)
	Pb	34	3.912	5.437±4.548	(0.917 - 17.88)
	Sr	34	6.764	7.913±4.034	(0.815 - 17.18)
	Ti	34	13.30	13.82±3.346	(3.249 - 23.35)
	Zn	34	185.2	215.7±151.1	(26.74 - 775.1)
Totok	As	15	1.230	1.439±1.070	(0.710 - 4.914)
	Cd	15	0.058	0.074±0.054	(0.013 - 0.195)
	Cr	13	4.106	6.637±9.401	(1.708 - 36.09)
	Ga	15	0.055	0.061±0.030	(0.023 - 0.144)
	Mo	15	0.066	0.073±0.038	(0.032 - 0.164)
	Sb	15	0.064	0.082±0.078	(0.028 - 0.342)
	Se	15	1.525	1.586±0.477	(1.053 - 2.544)
	Tl	15	0.032	0.082±0.148	(0.005 - 0.474)
	V	15	0.446	0.577±0.422	(0.182 - 1.454)
	Al	15	13.97	18.25±15.92	(3.707 - 66.51)

	Cu	15	9.494	10.65±6.056 (5.711 - 24.89)
	Mn	15	3.391	4.710±4.095 (0.894 - 14.58)
	Ni	14	0.930	1.449±1.221 (0.174 - 3.459)
	Pb	15	5.475	8.421±12.83 (1.637 - 53.90)
	Sr	15	4.357	5.297±3.927 (1.880 - 13.97)
	Ti	15	12.20	12.52±3.121 (8.491 - 19.22)
	Zn	15	176.0	189.0±82.80 (120.2 - 410.8)

		n	Geomean (µg/g)	AV (µg/g) ± SD	(min - max)
Total	As	49	0.625	0.784±0.743	(0.235 - 4.914)
	Cd	49	0.054	0.071±0.063	(0.011 - 0.387)
	Cr	47	3.964	5.769±6.771	(1.398 - 36.09)
	Ga	49	0.094	0.113±0.068	(0.023 - 0.280)
	Mo	49	0.056	0.061±0.027	(0.022 - 0.164)
	Sb	49	0.044	0.057±0.054	(0.013 - 0.342)
	Se	49	1.288	1.338±0.394	(0.735 - 2.544)
	Tl	49	0.006	0.028±0.088	(0.001 - 0.474)
	V	49	0.376	0.446±0.288	(0.095 - 1.454)
	Al	45	18.26	25.97±19.15	(0.064 - 96.22)
	Cu	49	9.059	9.954±4.373	(1.721 - 24.89)
	Mn	49	5.793	8.352±6.482	(0.505 - 24.53)
	Ni	48	1.092	1.541±1.400	(0.174 - 8.255)
	Pb	49	4.336	6.350±8.012	(0.917 - 53.90)
	Sr	49	5.912	7.112±4.144	(0.815 - 17.18)
	Ti	49	12.95	13.42±3.303	(3.249 - 23.35)
	Zn	49	182.3	207.5±133.6	(26.74 - 775.1)

	No.	As	Cd	Cr	Ga	Mo	Sb	Se	Tl	V	Al	Cu	Mn	Ni	Pb	Sr	Ti	Zn
Buyat	1	0.572	0.086	2.124	0.240	0.057	0.046	1.243	0.003	0.474	-	7.773	17.01	1.255	8.701	11.78	15.75	775.1
	2	0.279	0.036	2.358	0.280	0.064	0.017	1.283	0.001	0.527	-	7.893	15.73	3.524	1.900	14.70	17.77	182.8
	3	0.551	0.114	1.933	0.138	0.054	0.049	0.967	0.005	0.462	-	9.696	16.13	2.583	5.025	9.304	14.02	133.7
	4	0.432	0.034	5.113	0.098	0.043	0.025	0.925	0.001	0.295	40.02	1.721	1.837	1.121	1.886	4.081	7.607	264.3
	5	0.793	0.041	14.53	0.068	0.078	0.036	1.416	0.007	0.726	96.22	11.32	9.687	3.104	3.200	5.041	14.61	179.1
	6	0.335	0.042	2.523	0.177	0.044	0.031	0.960	0.002	0.180	35.35	12.55	10.25	1.233	3.410	6.037	13.25	264.6
	7	0.434	0.019	3.459	0.055	0.042	0.022	1.353	0.002	0.273	27.01	6.604	10.68	1.215	1.056	8.321	14.97	129.0
	8	0.446	0.123	2.055	0.142	0.047	0.095	0.834	0.003	0.570	59.05	14.24	8.273	1.500	14.67	6.153	13.58	179.3
	9	0.587	0.054	3.463	0.174	0.033	0.046	1.400	0.004	0.453	26.01	11.41	5.557	1.520	6.213	4.905	12.15	227.2
	10	0.823	0.113	2.491	0.213	0.074	0.135	1.035	0.010	0.482	33.36	19.43	16.21	1.615	12.40	10.83	14.00	160.2
	11	0.487	0.128	1.520	0.112	0.076	0.073	0.897	0.005	0.299	42.70	15.24	24.53	1.767	7.035	11.97	14.61	176.5
	12	0.235	0.074	1.398	0.106	0.046	0.044	0.907	0.002	0.273	32.68	6.149	14.06	8.255	6.736	17.18	23.35	736.7
	13	0.518	0.049	2.280	0.240	0.047	0.026	1.483	0.003	0.474	34.23	9.547	6.579	0.489	6.022	4.947	13.36	150.9
	14	0.401	0.011	13.04	0.175	0.064	0.031	1.075	0.004	0.319	32.04	7.933	3.214	1.865	1.845	2.720	11.50	160.9
	15	0.394	0.046	2.572	0.247	0.045	0.035	1.021	0.005	0.331	52.21	9.963	6.685	1.246	6.286	8.394	16.34	157.0
	16	0.725	0.083	3.267	0.115	0.046	0.053	0.979	0.004	0.354	17.01	6.742	22.94	0.632	6.499	14.35	17.17	240.9
	17	0.297	0.046	3.181	0.086	0.022	0.026	1.331	0.002	0.376	30.66	10.40	22.18	1.133	3.135	15.90	18.93	177.7
	18	0.345	0.061	20.53	0.166	0.075	0.029	0.910	0.002	0.336	13.61	8.706	8.977	3.248	2.428	9.403	14.09	214.9
	19	0.357	0.028	1.564	0.207	0.037	0.015	1.386	0.003	0.095	9.096	8.647	2.604	1.485	1.831	5.520	12.05	150.0
	20	1.017	0.165	7.831	0.178	0.098	0.071	1.086	0.012	0.721	57.34	10.31	11.24	1.685	6.929	6.165	12.93	174.5
	21	0.272	0.050	3.280	0.156	0.032	0.022	1.201	0.002	0.239	18.89	11.24	12.74	0.377	3.880	6.799	13.41	173.7
	22	0.406	0.046	3.055	0.232	0.046	0.021	1.673	0.005	0.435	39.54	10.63	5.674	0.549	1.257	5.976	13.09	167.3

	23	0.512	0.029	2.330	0.045	0.032	0.013	1.452	0.003	0.292	0.064	2.271	0.505	0.261	0.917	0.815	3.249	26.74
	24	0.839	0.029	6.091	0.028	0.087	0.149	1.707	0.003	0.952	13.04	12.26	1.542	1.074	17.88	7.264	11.67	114.5
	25	0.488	0.014	26.14	0.111	0.081	0.021	1.595	0.005	0.692	8.632	6.946	5.262	3.535	2.700	1.930	11.31	170.4
	26	0.562	0.124	5.340	0.158	0.076	0.084	0.735	0.002	0.475	30.57	9.672	5.096	1.310	11.37	4.396	11.97	167.9
	27	0.763	0.034	3.806	0.072	0.040	0.069	1.326	0.005	0.310	37.33	9.919	4.329	0.519	10.47	3.783	12.26	119.9
	No.	As	Cd	Cr	Ga	Mo	Sb	Sc	Tl	V	Al	Cu	Mn	Ni	Pb	Sr	Ti	Zn
Buyat	28	0.481	0.027	4.153	0.078	0.077	0.021	1.232	0.003	0.220	5.130	9.413	20.46	0.784	1.988	10.84	16.04	171.0
	29	0.467	0.040	4.759	0.085	0.041	0.028	1.859	0.003	0.188	12.24	5.550	3.466	0.215	1.998	6.001	11.72	156.2
	30	0.568	0.048	9.979	0.067	0.055	0.027	1.144	0.001	0.199	14.18	9.220	13.78	0.985	2.241	9.341	14.61	231.7
	31	0.276	0.387	3.528	0.100	0.066	0.128	1.218	0.001	0.435	41.74	11.83	16.41	0.585	15.75	7.923	13.56	434.7
	32	0.353	0.052	3.789	0.165	0.059	0.030	1.056	0.001	0.306	15.35	10.51	4.252	0.373	2.405	10.96	14.72	153.2
	33	0.542	0.100	9.935	0.072	0.069	0.049	1.977	0.006	0.187	19.74	14.83	9.068	1.482	3.791	11.37	18.14	229.1
	35	0.269	0.031	1.469	0.049	0.043	0.013	1.109	0.003	0.260	-	7.479	1.623	1.179	0.995	3.947	12.07	183.2
Totok	36	1.000	0.048	12.65	0.053	0.092	0.074	1.891	0.028	0.390	14.41	7.933	4.465	2.632	4.105	5.497	11.54	153.4
	37	2.308	0.058	3.439	0.054	0.043	0.046	1.488	0.017	1.051	11.75	7.879	3.814	0.435	5.445	2.292	10.61	123.0
	38	0.858	0.013	2.047	0.051	0.036	0.034	1.254	0.015	0.456	20.03	6.832	2.867	2.460	1.637	4.125	11.89	164.8
	40	4.914	0.093	2.622	0.070	0.056	0.110	1.109	0.022	1.087	24.35	10.41	9.443	0.174	6.413	2.786	12.53	208.5
	41	1.709	0.164	4.218	0.052	0.068	0.108	1.167	0.026	0.889	21.17	7.930	2.371	0.323	6.049	3.422	11.48	123.5
	42	1.078	0.023	1.708	0.040	0.065	0.034	1.312	0.005	0.271	14.81	8.093	0.894	-	3.311	3.984	11.19	120.2
	43	0.820	0.028	-	0.023	0.079	0.036	1.077	0.010	0.194	5.297	7.412	2.634	3.459	4.058	1.880	9.489	154.7
	44	0.710	0.063	3.811	0.038	0.095	0.037	1.475	0.020	0.204	8.882	11.11	2.657	0.481	5.102	4.801	10.65	220.9
	45	1.025	0.031	2.293	0.047	0.032	0.028	1.554	0.014	0.182	7.606	6.974	2.180	1.236	3.407	3.302	11.81	120.9
	46	1.217	0.036	2.049	0.144	0.058	0.061	1.672	0.409	0.183	3.707	5.711	1.008	0.415	3.236	4.161	12.50	410.8

47	1.280	0.195	9.135	0.087	0.164	0.342	1.680	0.105	1.076	66.51	24.89	14.58	2.714	53.90	13.81	19.22	162.0
48	0.784	0.076	2.716	0.052	0.037	0.095	1.053	0.474	0.249	11.55	6.531	1.494	0.272	5.495	3.250	8.491	183.6
49	1.140	0.144	36.09	0.092	0.144	0.084	2.493	0.022	1.454	37.91	19.62	9.365	3.201	12.46	9.529	17.73	236.9
50	2.000	0.058	-	0.036	0.052	0.045	2.015	0.038	0.610	16.91	7.279	2.974	1.873	3.809	2.648	11.09	129.8
51	0.748	0.083	3.501	0.069	0.079	0.092	2.544	0.031	0.360	8.882	21.12	9.912	0.609	7.881	13.97	17.52	322.4

Reference	As	Cd	Cr	Ga	Mo	Sb	Se	Tl	V	Al	Cu	Mn	Ni	Pb	Sr	Ti	Zn
NIES No.13	0.10	0.23	-	-	-	0.042	1.79	-	0.27	120	15.3	3.9	-	4.6	-	-	172